Complexes of Stars and Complexes of Star Clusters

Yu.N. Efremov
Sternberg Astronomical Institute, Moscow, Russia
e-mail: efremov@sai.msu.ru

Abstract

Most star complexes are in fact complexes of stars, clusters and gas clouds; term "star complexes" was introduced as general one disregarding the preferential content of a complex. Generally the high rate of star formation in a complex is accompanied by the high number of bound clusters, including massive ones, what was explained by the high gas pressure in such regions. However, there are also complexes, where clusters seems to be more numerous in relation to stars than in a common complex. The high rate of clusters - but not isolated stars - formation seems to be typical for many isolated bursts of star formation, but deficit of stars might be still explained by the observational selection. The latter cannot, however, explain the complexes or the dwarf galaxies, where the high formation rate of only stars is observed. The possibility of the very fast dissolution of parental clusters just in such regions should itself be explained. Some difference in the physical conditions (turbulence parameters first of all) within the initial gas supercloud might be a reason for the high or low stars/clusters number ratio in a complex.

1 Introduction

The common opinion is that formation of star clusters is the only way of star formation. Since 1950s we know that the stars forms by groups, in clusters and associations. The presently isolated stars might be formed in groups, which have been dissolved till the present time.

Most star complexes are in fact complexes of stars, clusters and gas clouds; term "star complexes" was initially suggested for all of them, disregarding what is their preferential or more evident population [1, 2]. However, later on we have presented evidences for existence of complexes, where clusters seems to be more numerous in relation to stars than in a common complex [3]. Some difference in the physical conditions within the initial gas supercloud might be a reason for such high C/S number.

We present here more examples of locations where the rate of cluster formation seems do not correlate well with the rate of the isolated star formation. These cases are to be studied in more details. The high C/S ratio might be explained by the observational selection, but it is more difficult for the low C/S ratio. The plausible

explanation of low C/S ratios by the very fast dissolution of parental clusters just in such regions should itself be explained.

2 The young massive clusters

The related issue is what are conditions which lead to formation of the young massive clusters (YMCs). The most massive of the YMCs are bound, being the the progenitors of the classic (old) globular clusters for the future times. In other wording, observed now bound YMCs looks like it had have to be the case for the classic present day globulars some 10 Gyr ago.

The results of the systematic search for the YMCs, performed by Larsen and Richtler [4] in 21 spiral galaxies lead these authors to conclusion that the number of such clusters (normalized to the luminosity of the parent galaxy) correlates with the star-formation rate (SFR) per unit of area of the corresponding galaxy. These authors concluded that the formation of numerous YMCs in interacting and starburst galaxies can be explained by the same mechanisms as in the case of normal galaxies, but operating under extreme conditions. Whitmore [5] corroborated this conclusion and found that the relation between the SFR and the occurence of YMCs found by Larsen and Richtler [4] can be extended to these galaxies. These results seems to be the strong confirmation of the conclusion that the general high SFR is going along with the high occurence of star clusters.

There are well based theoretical reasons for the formation of massive bound clusters in the regions of the high SFR, because there the high pressure conditions should exist ([6], [7], [8]. The high pressure (density) surroundings may prevent the dissolution of even very massive newborn clusters, in spite of their O-stars and SNe pressure to the intracluster gas. This mechanism is evidently in action within the bursts of star formation in the interacting galaxies, and in the regions of the high SFR generally, like it was shown in [4] and [5].

There are however the important exclusions. A few of the BCD galaxies host very luminous YMC (known as star superclusters, SSC), which are far above the relation between the SFR and the luminosity of the brightest in a galaxy cluster [9]. Something else was probably in action.

The lower abundance which is often observed in the dwarf galaxies might act to the same direction; however, the difference in the parameters of the turbulence in the insterstellar gas may be the most important factor to determine the mode of the star formation. The latter is presumably a fast process, determined mainly by the interplay of gravitation and turbulence (Elmegreen [10]) and the fast free collapse of molecular cloud is prevented not by magnetic field but by turbulence (see, however, Muchovias [11]). Its parameters might determine whether the bound or fast dissolving clusters form predominantly.

Klessen et al. [12, 13] suggested that the decaying or long-wave turbulence results in fast formation of bound clusters, whereas the isolated field stars form in the case of shorter wavelengths. Inefficient and isolated star formation occur in such regions, but the velocity structure in molecular clouds is dominated by large scale turbulent modes. If the self-gravity overwhelms turbulence, due to compression by a large-scale shock or to fast decay of turbulence, the bound clusters are formed. A

small scale turbulence requires un unrealistically large number of driving sources, what explains why most stars in the Galaxy formed in open clusters, as found in [14].

If so, the properties of turbulence might be different within the whole star/cluster complex (or even in a draft galaxy) and this may be able to explain the different S/C ratios in different regions.

3 Complexes of stars and complexes of clusters

There are indeed the rare complexes of only clusters and complexes of only isolated stars; the most striking samples are known in the LMC. Inside the group of a dozen coeval clusters around NGC 2164 (four of these are the YMCs) in the LMC only three Cepheids are known (and a few more inside clusters), although this complex has an optimum age for Cepheid stage of massive star evolution (fig. 1).

While searching for the local agent responsible for formation of either star clusters or isolated stars, it is important to deal with the objects of the same age. The Cepheid stars are easy detectable and their ages are known from the period - age relation well established both from observations [15] and the theory [16]. An objective comparison of the distributions of Cepheids and clusters of the same age as Cepheids in the LMC yielded, apart from NGC 2264 group, three more groups of clusters, and only one of these four groups of clusters was found to coincide with a Cepheid concentration (Battinelli and Efremov [17]). It follows from the results of the OGLE program (search for the variable stars) that this group, located immediately at the East tip of the LMC bar around the young massive massive clusters NGC 2058 and NGC 2065, contains about twenty smaller clusters and about 150 Cepheids of which 20 are cluster members. This complex might be considered to be normal in cluster/star ratio.

Immediately southeast of this NGC 2058/2065 complex there is a dense group of about the same size (200 x 300 pc), which hosts 180 Cepheids and no conspicuous clusters. The central part of this group is devoided of any clusters completely, whereas the density of Cepheids there is about 900 per kpc^{-2}, i.e., by two orders of magnitude higher than in the solar neighborhood. The periods, and consequently, the ages of most of these Cepheids are confined within a narrow interval (3–5 days). It follows from the age spread and stellar density that this complex of Cepheids is a relic of a star-formation burst - some 50-100 Myr ago there was indeed the very high local SFR. However, this did not lead to formation of star clusters - or, at least, only small and fast dissolving clusters were formed there (fig. 2).

The compact groups of clusters are seen also in the ACS HST image of the M51 galaxy. Some of them are within the spurs, which might be the essential clue to seemingly unnormal C/S ratio within these groups (fig. 3). This ratio is to be studied yet with data on the fainter stars.

4 Discussion

The superassociatons or the localized bursts of star formation are nothing but the star/cluster complexes, involved totally in the intensive star formation process; most of them are the supergiant HII regions. However, it is not the case for NGC 205 = OB 78 superassociation in M31. This 1 kpc in size region is filled with OB-stars; a few small HII regions are near, but outside, of it (fig. 4). This was explained long ago by the lack of the gas inside OB78 - the gas was therefore expulced??? from the superassociation by the pressure from O-stars/SNe earlier than it was ionized. This plausibly was due to the high density of these stars; this suggestion might be checked by the observational data on stars and gas in this region - and also in M51, where the very various interrelations between HII gas and star/cluster complexes are seen and are to be studied. Anyway, our present goal is to stress the absence of star clusters inside OB 78. This is an evident contradiction to the high pressure explanation of the formation of the bound massive clusters. Moreover, this case is dissimilar to many other localized bursts of star formation, where just the YMCs, if not SSCs, dominate, like it is the known case in the Antennae galaxies, and, to lesser extension, inside the M101 supergiant HII regions.

Somewhat similar case is IC 10, the dwarf galaxy of the Local group. The current rate of star formation there is the highest of the all Local Group galaxies, but no YMCs are known there (Grebel, [18]). As S.Larsen has commented, "may be there is someting peculiar going on there" ([18], p. 427).

The very low cluster formation rate is known in the irregular Local Group galaxy IC 1613. Being normalized to the same star-formation rate, it is 600 times lower than in the LMC, which is a galaxy of the same type [19]. The quite low number of star clusters in IC 1613 has been known since W.Baade's investigations in Fifties. This led Hodge (Galaxies, 1986) to conclusion that the unrecognised agent should exist, determining whether the formation of the populous clusters is possible in a galaxy or not. Anyway, 13 OB-associations and even a superassociation, noted by W.Baade, are known in IC 1613. Therefore, it looks like this agent is not always the dierect consequence of the general SFR.

There may exist not only local, but also temporal difference in the clusters and stars rate of formation. At least in the LMC it is the case. The break in the formation of (at least massive) clusters, which lasted in the LMC for 4–14 Gyr, was not matched by a decrease in the star-formation rate (van den Bergh [20]). The conclusion by van den Bergh was: "The dramatic contrast between the history of the cluster formation and that of field stars suggests that star clusters cannot be used as proxies for star formation".

The steep IMF found by Massey [21] for the seemingly isolated stars of the LMC field might be considered the indication of different mode of formation for isolated stars, but recently Elmegreen and Scalo [22] concluded that this steeper IMF resulted from unappropriate assumption of the constant SFR, which is hardly is justified for the field stars.

All in all, these data demonstrate the important and often unrecognised problem does exist and should be carefully investigated. The best approach to this issue seems to be studying the populations of the same age within isolated star/cluster complexes in resolvable galaxies. (The data on the MW galaxy suffered from many

selection effects and uncertainty of distances; anyway, they suggest also the existence of complexes of clusters, like the compact group in Cassiopeia, described in [3], p. 204).

The objects within a complex have arised from the (initially) bound gas supercloud and the ISM properties within it must be reflected in stars/clusters number ratio over all the complex. This ratio for the objects of the same age should be determined for the large number of the best outlined complexes in different galaxies and at different location within a galaxy. The Cepheid investigations would be valuable, yet considering these are time-consuming and age-limited, the data on the bright stars could be used up to the same magnitude limit in a galaxy.

The position of a complex in a galaxy might be connected with the value of stars/clusters ratio inside the complex. There are indeed some guesses that this might be the case. OB78 in M31 seems to locate at the cross of two spiral arms going to opposite directions. In the LMC, the NGC 2164 group of clusters is in isolated position far from the LMC center, whereas the NGC 2058/2065 group is near the tip of the bar and the dense group of Cepheids is to SW of it. The bright complexes are often at the tips of the spiral arms, whereas in the grand design galaxies complexes are often located at equal spacing along the arm, suggesting the formation under action of Parker instability. The different mechanisms of formation may be reflected in the different clusters/stars ratio and parameters of turbulence in ISM might depend on a position inside a galaxy.

The peculiar shape may also be connected with the certain mechanism of formation and C/S ratio. The arc-shaped complexes might be formed in result of the dynamical pressure. The arc-like shape has been observed too at the all-galaxy scale, for the leading edges of a number of galaxies moving through the IGM, i.g. for DDO 265 in M81 group (fig. 5). More examples are given in [23]. Note that the arcs of Sextant in the LMC and that of the Western complex in M83 consist of 5 - 7 clusters each, whereas the older arc of Quadrant consists from both clusters and stars [24]. The star formation triggered by the high (especially dynamical?) pressure may result mostly in the bound clusters, whereas gravitational fragmentation of a supercloud probably lead to the normal (most often observed) C/S ratio. This is surely the most frequent case of a star/cluster complex formation. However, the low C/S ratio in regions presumably formed under the high pressure conditions, which demonstrate the high SFR, seems to be not only rare, but also enigmatic cases.

The issue of the mode of star formation might have the deep cosmological implications. For example, the formation of the YMC (and more so of the SSC) in the BCD galaxies, many of which are isolated, miight be triggered by gas infalling in dark-matter haloes; this gas may experience sloshing and oscillation favoring compressiion and instabilities [25].

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Fugure captions

Fig. 1. The group of YMCs around NGC 2164 in the LMC. DSS image.

Fig. 2. a) The DSS image of the LMC field near the bar Eastern tip, including the NGC 2065 and NGC 2058 clusters at the upper right and the region of the highest density of Cepheids at bottom left. b) The map of the same region, constructed with the programe OGLE data. The crosses are Cepheids.

Fig. 3. a) The largest spur in M51, starting at the West of the spiral arm. It includes large star clusters. b) The detail of the fig. 3a - group of the star clusters located near the starting point of the spur. c) The star clusters inside the SW spur, starting from the same M51 arm. It looks like these positions are favorite for the formation of bound clusters. The images are details of the ACS HST image.

Fig. 4. The bright complex (localized starburst) NGC 205 = OB78 located at the crossing of the spiral arms S4 and S3 in M31.

Fig. 5. The dwarf galaxy DDO 265 in M81 group. Image taken at the BTA.